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The Electrolytic Corrosion
of Brasses

Chemistry

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THE ELECTROLYTIC CORROSION
OF BRASSES

BY

DAVID KLEIN, A.B.
AND
PAUL E. HOWE, B.S.

THESIS

FOR

DEGREE OF MASTER OF ARTS

IN

CHEMISTRY

IN THE

GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

PRESENTED JUNE, 1907

UNIVERSITY OF ILLINOIS

May 31

1907.

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

David Klein, A.B. and Paul E. Howe, B.S.

ENTITLED The Electrolytic Corrosion of Brasses

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Master of Arts

in Chemistry.

A. G. Lincoln

Instructor in Charge.

APPROVED:

Hubert

HEAD OF DEPARTMENT OF

Chemistry

191921

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David Elzer, L.D., and David Elzer, L.D.

The Elzer family of Elzer, L.D.

David Elzer, L.D.

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The extensive use of brass for industrial purposes, especially in the various parts of hydraulic machinery and boats, makes it very desirable that a scientific study be made of the corrosive effect of solutions on the brasses. It might be well at the outset to state clearly what we understand by the term "corrosion". Brass exposed to the action of climatic changes soon becomes green; silver exposed to smoke blackens, and we commonly say it has tarnished; iron develops a reddish coating, called "rust"; dissimilar metals in contact in sea-water are rapidly disintegrated; iron water-mains in large cities are ruined by the corrosive action of stray electric currents. From these few examples, it must be quite clear that all the above changes are chemical, no matter what caused the reaction. Acids act on metals to form salts; this is acid or chemical corrosion. An electric current may disintegrate the anodic material; this is electro-chemical corrosion. Are these two forms of corrosion the same? Many decades ago the answer was made in the affirmative, and quite recently Mr. Turrentine (1) demonstrated experimentally that the differences between the chemical and electro-chemical action of nitric acid on copper are due to dissimilar conditions in the experiments and not to any real differences in the nature of the action. Chemical corrosion of metals by salt solutions is a slow process; while the electro-chemical action is rapid. It was therefore the object of this research to study the electro-chemical corrosion phenomena of brasses in aqueous salt solutions, with the purpose of ultimately obtaining useful brasses that may be termed "non-

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corrosive".

Brasses will be considered as composed of copper and zinc in varying proportions; and to make things simpler, we shall distinguish the brasses by their copper content. Thus a 60 per cent. brass is one that contains 60 per cent. copper and 40 per cent. zinc. The question now arises are brasses merely mixtures of copper and zinc; or are definite compounds present? The determination of the various equilibrium phases is not at all an easy matter. Different methods yield very discordant results. For instance, Guertler (2) from his compilation of the work of others on the electrical conductivity of alloys arrives at the conclusion that copper and zinc combine in the proportions of Cu_2Zn_3 ; this compound would correspond to the boundary line between Shepherd's (3) α and β crystals. Herschkowitsch (4) from his single difference of potential measurements believes that zinc and copper form the compound CuZn_2 . We shall have occasion to refer to this work later. By thermometric and micrographic methods, Roberts-Austen (5) and more recently Shepherd (3) have established the various equilibrium phases. Since their methods are accurate and reliable, we have adopted Shepherd's classification, which is as follows:

Brasses are never compounds, but are solid solutions. At 400°C . brasses varying in composition from

100% Cu	-	63% Cu	contain the α crystals.
63% Cu	-	51% Cu	" " $\alpha + \beta$ "
51% Cu	-	40% Cu	" " $\beta + \gamma$ "
40% Cu	-	30% Cu	" " γ "
30% Cu	-	20% Cu	" " $\gamma + \epsilon + \delta$ "
20% Cu	-	13% Cu	" " ϵ "

13% Cu - 2.5% Cu contain the ϵ crystals.

2.5% Cu - 0% Cu " " " "

Brasses were prepared representing nearly all of these areas. It is to be regretted that brasses containing the γ crystals could not be used because of their extreme brittleness. Below 55 per cent. copper, brasses are not used commercially, but we have included them, in order to make the series complete.

The method of obtaining the brasses is as follows:- The desired amount of pure electrolytic copper was melted under a layer of charcoal in a crucible. When the copper was thoroughly molten, the zinc (the so-called Bertha spelter) was added in small quantities, and the melt vigorously stirred after each addition. In this way a little more zinc was lost by volatilization than would have been the case, if all the zinc were added at one time. However, by the latter method, the melt invariably "froze", and it was very difficult to remelt it. When the brass was ready to be "poured", the charcoal layer was carefully removed, the brass well mixed by means of a carbon rod, and rapidly poured into a sand mould.

After many months of discouraging trials with moulds of various types (carbon, iron, etc.), sand casting was resorted to, and gave very satisfactory results. The pattern consisted of a large brass rod (7" X 1/2") through which seven smaller brass rods (9" X 1/4") were inserted at equal distances. The mould was made in two parts, each receiving the impression of exactly one-half of the pattern. The upper half was then supplied with a "gate" in the middle and a "riser" at either end. With the mould thoroughly

vented, it was possible to secure very acceptable castings. After the brass had been "poured", it was removed from the mould as soon after solidifying as possible (Even while red-hot) and quenched in cold water.

The small rods were then cut from the "gate", and samples for analysis were obtained by filing and polishing two of the pieces and taking sections (about .5 gram) from opposite ends of either. The copper was determined by electrolysis, and duplicate analyses proved conclusively that the rods were of uniform composition. For example, the following are a few of such analyses:-

Per cent. Copper 86.66 - 86.66

73.38 - 73.44

58.52 - 58.46

51.42 - 51.48

If the analysis showed that the brass was of the desired composition, the test pieces were annealed at 400 C. for two weeks, in an electric annealing oven of the simple form described by Shepherd (3) the only difference being that German silver wire was found more satisfactory than nickel wire for resistance. The pieces were then machined down to 3/16" in diameter, highly polished, numbered and stored in glass-stoppered bottles, where they remained bright and clean after months' standing. In the manner described above, the following series of brasses was prepared:-

Per cent. Copper: 93.6; 86.6; 83.3; 76.3; 73.4; 66.5; 60.3 56.8; 51.3; 47.6; 22.6; 10.5; 3.1.

It was deemed advisable to corrode all the pieces of the series in the same electrolyte simultaneously, so the following

stirring device was constructed:- Along a wooden strip 1-1/2" X 1" at equal distances of about 5 inches, holes were drilled into which were driven short brass rods, whose centers were drilled out to fit 3/16" rods. These rods terminated at their lower ends in brass connectors to hold the test pieces, while the upper ends were made cup-shape to hold a drop of mercury and the leading-in wire for the current. Each stirrer, fitted with a two-grooved wooden pulley of uniform diameter was connected in series with the preceding stirrer by an elastic belt. The entire apparatus was raised about five inches above the desk to accommodate the beakers containing the electrolytes. Since it soon became evident that thirteen such stirrers in one apparatus were too unwieldy, the apparatus was divided so that one section contained six stirrers and the other seven. Each section was driven by a separate motor of the same pattern and speed.

The current was conducted in series through the test-pieces, thick platinum wires serving as cathodes. No attempt was made to have a current of the same strength in the different experiments, for reasons to be given later. In all cases 200 c.c. of the electrolyte were used, the concentration of the solutions being approximately normal. We experienced no trouble in the matter of the solute creeping up the sides of the beakers. When an experiment was concluded, each test-piece was carefully cleansed with a rubber-tipped stirring rod until no more material could be removed. It is important to call attention to this fact; that in many cases, especially in the earlier experiments, there often remained on the test-piece a copper-colored coating, which many times could not be

TABLE I A.

Corrosion in Sodium Chloride Solution.

% Cu.	Grams Corrosion	Grams Cu. Corrosion	% Cu. Corroded
93.6	.5657	.5230	92.4
86.6	.5262	.4122	78.3
83.2	.5190	.4147	79.9
76.3	.4901	.3657	74.6
73.4	.4852	.3566	73.5
66.5	.4603	.2869	62.3
60.3	.4364	.1996	45.7
56.8	.3639	.1022	28.1
51.3	.3350	.0514	15.3
47.6	.3021	.-----	-----
22.6	.3104	.-----	-----
10.5	.3006	.-----	-----
3.1	.3019	.-----	-----

TABLE I B

93.6	.7204	.6756	93.8
86.6	.7165	.6263	87.4
83.2	.6935	.5807	83.7
76.3	.6519	.4993	76.6
73.4	.6460	.5117	79.2
66.5	.6056	.4026	66.5
60.3	.5773	.3417	59.2
56.8	.4576	.1150	25.1
51.3	.4618	.0990	21.4
47.6	.4077	.0052	1.3
22.6	.4042	.0006	0.2
10.5	.3975	.0004	0.1
3.1	.3972	.0001	0.0

removed even by scraping with a knife. Most of the tests were run in duplicate, and some of them many more times. The results presented here can have no claim to absolute accuracy, but are simply useful in indicating the general trend of the corrosions.

Table I gives the results for the corrosion in a normal sodium chloride solution. After a few minutes corrosion the beakers contained light greenflocculent precipitates, which soon changed to a very dark yellow or orange color, in all cases except the three lower brasses, which remained almost pure white. No other electrolyte gives the same colored corrosion product, which is probably a mixture of the oxides. At the termination of the experiment, the pieces were coated with a heavy red scale, in most cases, easily removable. In one or two cases not even scraping was efficacious. That this tenacious scale is pure copper is readily seen from the following test. A day or two after the completion of an experiment (not shown in the tables) it was observed that the scale of the 51.3 per cent. brass was becoming loosened. Accordingly, the whole scale was removed (it could now be readily peeled off), weighed and analyzed. .3172 grams of the scale contained .3140 grams of copper, showing that 99 per cent. of it was copper. The copper in the corrosion products of series 1 A was determined by first separating the copper as the sulphocyanate, and electrolyzing its solution in nitric acid. The results are not to be regarded as equal in accuracy to those of table 1 B, wherein the copper was first deposited from an ammoniacal solution and subsequently from a nitric acid solution. It is interesting to note that the grams corrosion in both cases would give parallel curves for the entire series.

The choice of methods for graphically representing corrosion data is not an easy matter. In a paper similar to this one, on the corrosion of bronzes, Mr. Curry (6) expressed his results in current efficiency curves on the theoretical basis that all bronzes of intermediate compositions between pure copper and pure tin would corrode in the proportion of their constituents. The curves as given by him indicate that the amount of corrosion is greatly influenced by the phases in equilibrium. In no case, did he present similar curves for the copper or the tin efficiency. While attempting to plot such curves for the bronzes, this interesting fact soon became evident; that at certain composition more than 100 per cent. efficiency was obtained. This was especially true for sodium nitrate, ammonium nitrate and ammonium oxalate solutions. Upon comparison with Mr. Curry's data for the corrosion of bronzes in sodium nitrate solutions, the fact of more than 100 per cent. efficiency is observed for the low copper bronzes, all of which is explained by disintegration of the electrode. Another fact is connection with the bronzes that Mr. Curry seems to have overlooked is that the copper efficiency for the high copper bronzes is far above 100 per cent. Moreover, after each of the complete series run by Mr. Curry, he investigated more carefully certain bronzes emphasizing the fact that the ϵ crystals were removed from the solution before analysis. From this it would appear that the ϵ crystals are a disintegration product, and as such are not to be included as part of the current efficiency, as done by Mr. Curry. These considerations, as well as others gathered from our own experiments, lead us to the belief that in the true sense of the word,

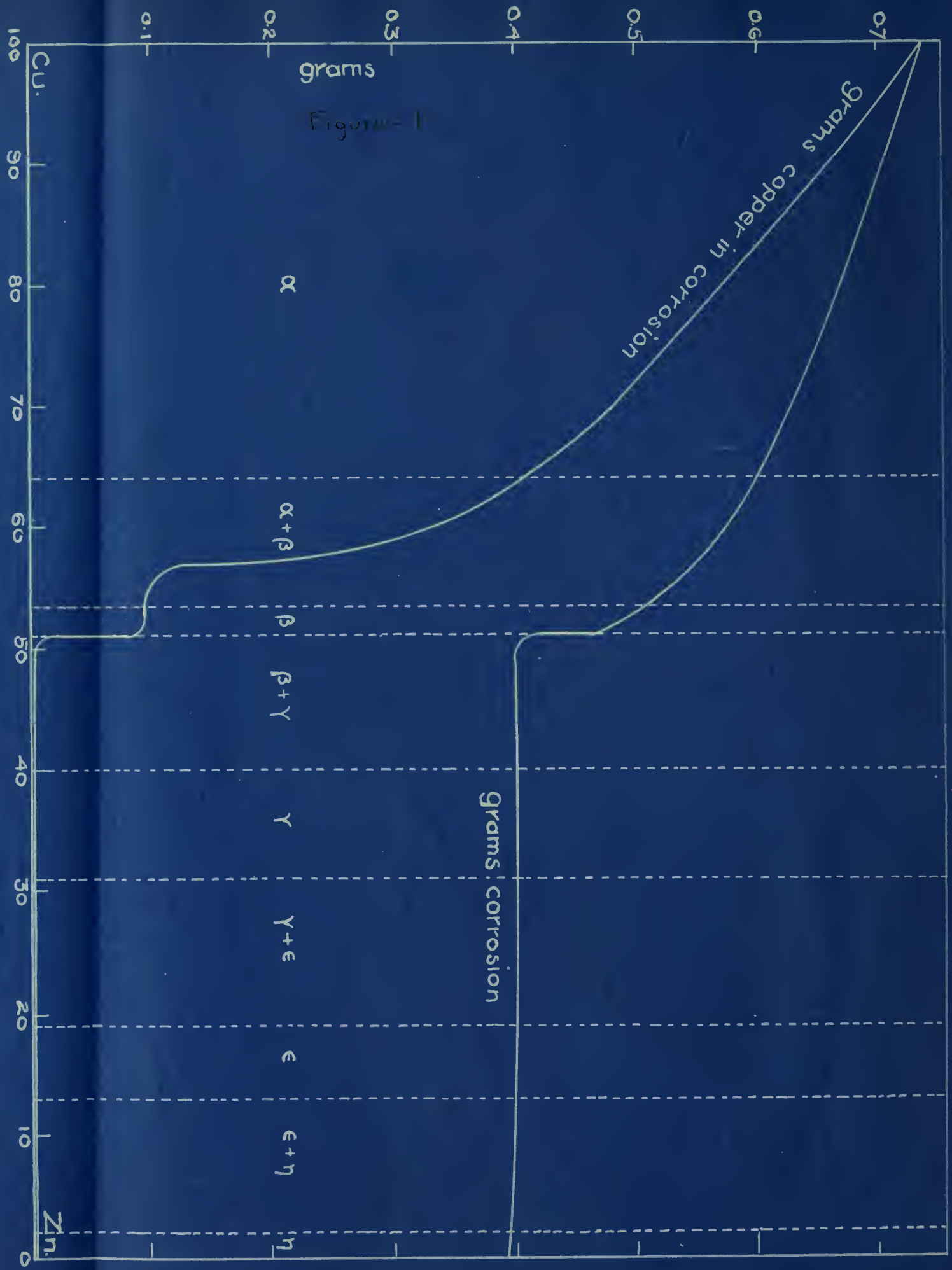
no current efficiency diagrams can be plotted, and that factors other than the mere electrical current govern the corrosion.

To make our position a little clearer, let us take for example, the electrolysis of a sodium nitrate solution between a platinum anode and cathode. At the cathode, the sodium ion giving up its charge forms sodium hydroxide, liberating hydrogen. At the anode, the nitrate radical liberates oxygen with the reformation of nitric acid. If the solution is well mixed, the sodium hydroxide and the nitric acid react to produce sodium nitrate. If, however, we employ a copper anode, instead of oxygen being liberated, copper nitrate will be formed, which, reacting with the sodium hydroxide, precipitates copper hydroxide. The only difference in the two cases cited is that the anodic product of electrolysis does not react chemically with the anode in the first case, but does so in the second. If we had employed a pure zinc anode, the experiment would have been analogous to the one where copper was the anode. However, if we employ, as an anode, a brass of any composition, we complicate matters greatly. On the assumption that copper and zinc only are present, and each acts independently of the other, the nitrate ion has a selective action. It may take either the copper or the zinc or both. Clearly it is a case of the distribution of two metals between an acid.

Now, it is well known, that besides the copper and zinc, various crystalline mixtures (solid solutions) of these elements exist in brasses. In that event, the nitrate ion may dissolve either copper, zinc, the crystals, or any combination of these. If it dissolves the copper and the zinc according to the concen-

tration of these elements and without regard to the form in which they exist, then the composition of the corrosion product will be the same as the test-piece from which it was produced. If, however, phases have any effect on the solvent action, then it must be admitted as likely that a combination of zinc and copper may be obtained that will be passive or tend to become so. In that case, it will dissolve less slowly than the rest of the test-piece, but as the matrix is eaten away, the crystal will fall out mechanically; and if not removed from the solution before ^{dissolving} the corrosion product in nitric acid and analyzing, it will be considered as part of the product directly due to the current, and consequently enter into the efficiency diagram. This then gives an excellent basis for values higher than the theoretical efficiency. But the same phenomenon is taking place in brasses and bronzes, which even on the erroneous basis of current efficiency, gives less than the calculated values. In that case the true results must be lower. In actual chemical corrosion, the disintegration products will be removed from the brasses, after the corrosion has proceeded far enough and should therefore be considered as loss by corrosion.

For these reasons we have not attempted to plot any current efficiency curves but have adopted the plan of showing the change in actual grams' corrosion with the composition. It must be distinctly understood that no attempt was made to keep the current up to the same ampereage throughout these experiments. Therefore, the diagrams can only show the relative corrosion of the various brasses in the same electrolyte. Whether such corrosion will take place, depends upon the electromotive force that will be set



up in the solution; since the passage of a current and the resulting corrosion will depend upon the decomposition voltages of the solutions and the potential differences of the brasses. It is therefore purposed in the near future to measure the potential differences of brasses in the various solutions used, and thus perhaps gain an insight into the relative corrosion power of various electrolytes. Another means of accomplishing the same end will be discussed later in this paper.

Figure I illustrates the relative corrosion of the various test-pieces in sodium chloride solutions; the data are given in table 1B. For the total grams corrosion and copper corrosion there is a rapid and regular decrease in the amount corroded as the copper content of the brass decreases. At 51 per cent. copper there is a very marked falling off in the amount of the corrosion due to the presence of the γ phase, which first appears at that point. It is interesting to note that from 50 per cent. copper to pure zinc practically no copper is found in the corrosion product. From this it follows that in the γ , ϵ and η phases, we have good examples of the selective action of the acid present. The fact that almost no copper dissolves from brasses of less than 60 per cent. copper accounts for the presence of the copper films mentioned above. Above 60 per cent. copper, the brasses do not become so copper-rich on the surface and dissolve in the proportion of the original test-piece.

After the completion of the experiment, the brasses were examined microscopically, with very surprising results. Description of the appearance of the electrodes would give an inadequate idea of their crystalline structures, so we shall not describe

TABLE II A.

Corrosion in Sodium Nitrate Solution.

% Cu.	Grams Corrosion	Grams Cu. Corrosion	% Cu. Corroded
93.6	.2617	.2410	92.1
86.6	.2591	.2240	86.5
83.3	.2773	.2236	82.5
76.3	.2746	.2024	73.7
73.4	.2782	.2044	73.5
66.5	.2618	.1562	60.0
60.3	.2960	.1776	60.0
56.8	.2774	.1500	54.1
51.3	.2786	.1494	53.6
47.6	.2855	.1018	35.7
22.6	.2111	----	----
10.5	.2717	.0125	4.6
3.1	.3916	.0116	3.0

TABLE II B.

93.6	.3091	.2877	95.2
86.6	.3191	.2775	86.9
83.3	.3173	.2645	83.4
76.3	.3308	.2494	75.4
73.4	.3375	.2481	75.2
66.5	.3398	.2238	65.8
60.3	.3452	.2105	61.0
56.8	.3355	.1872	55.8
51.3	.3375	.1812	53.7
47.6	.3504	.1516	43.2
22.6	.2352	.0002	0.0
10.5	.3316	.0228	6.8
3.1	.4804	.0174	3.6

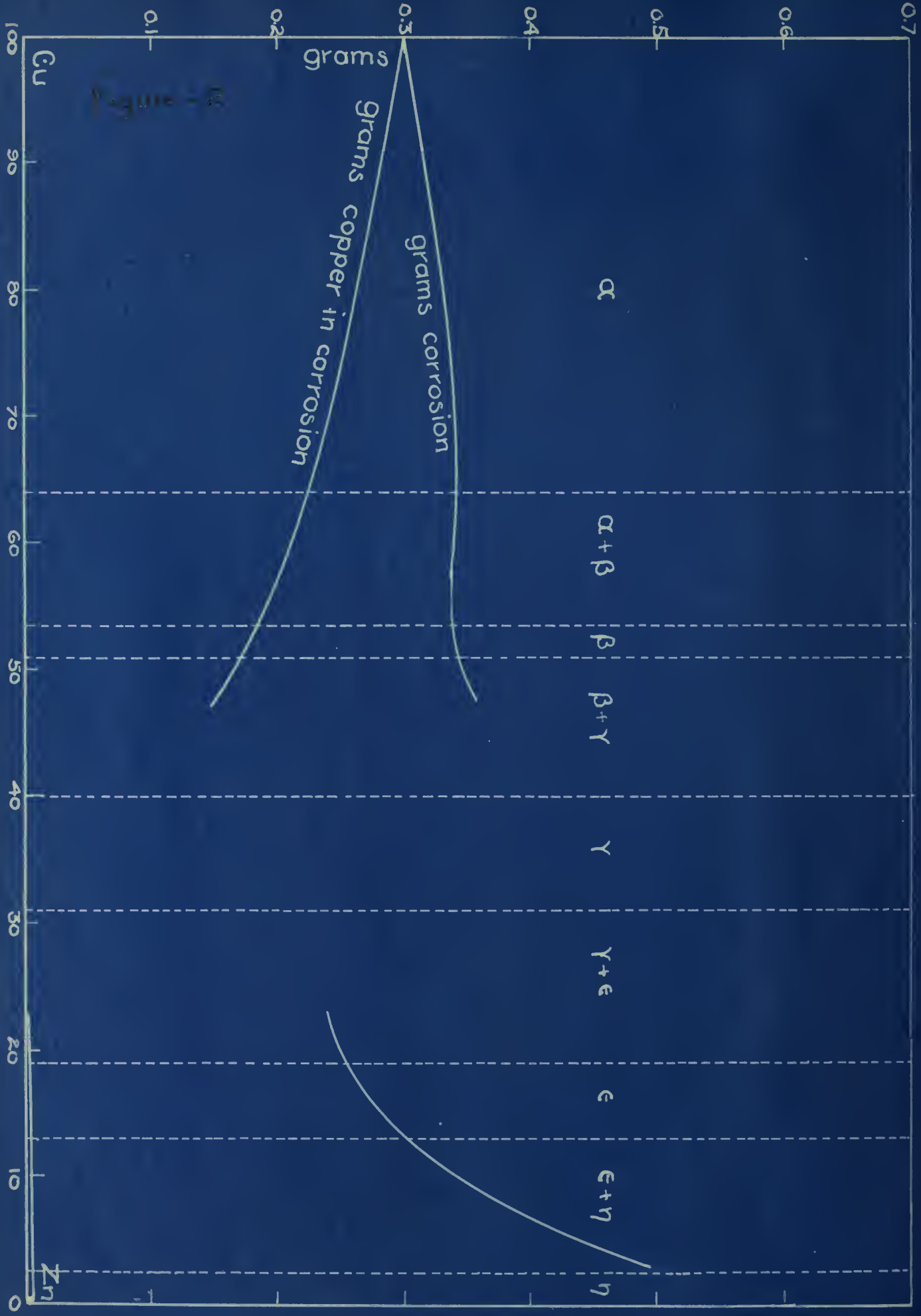


Figure 1

them in detail. There seems to be a definite relation between the appearance of the test piece after corrosion and the phases in equilibrium; in other words, this method of electrical etching gives results comparable with acid etching. We shall reserve a more detailed discussion until some later date, when more work has been done on the subject.

The results for two series in sodium nitrate solutions are given in Table II and shown graphically in Figure 2 for series 2A. In these cases, the corrosion products were apparently hydroxids of copper and of zinc in varying proportions. In the case of the 3.1 per cent. brass, the corrosion product was gray-colored due to metallic particles mixed in with the zinc hydroxide. The test-pieces were coated with a red-scale, easily removable and exposing the structure of the brass underneath. From Figure 2, it is at once evident that the amount of corrosion increases with the decrease of copper content in the test-piece. For the 22.6 per cent. brass, the corrosion is lower than for any other concentration studied. But the corrosion very rapidly increases as the zinc content increases. A prolongation of the curve to the zinc axis would lead to the conclusion that pure zinc corrodes as a mono-valent metal--an absurdity. Pieces of pure copper and pure zinc were corroded in series with a copper voltameter with the following results:-

Cu	.3922	.3719)	) Grams corroded
Zn	.3656	.3763)	
Voltameter	.3719	.3497	grams deposited.

grams

Figure 3

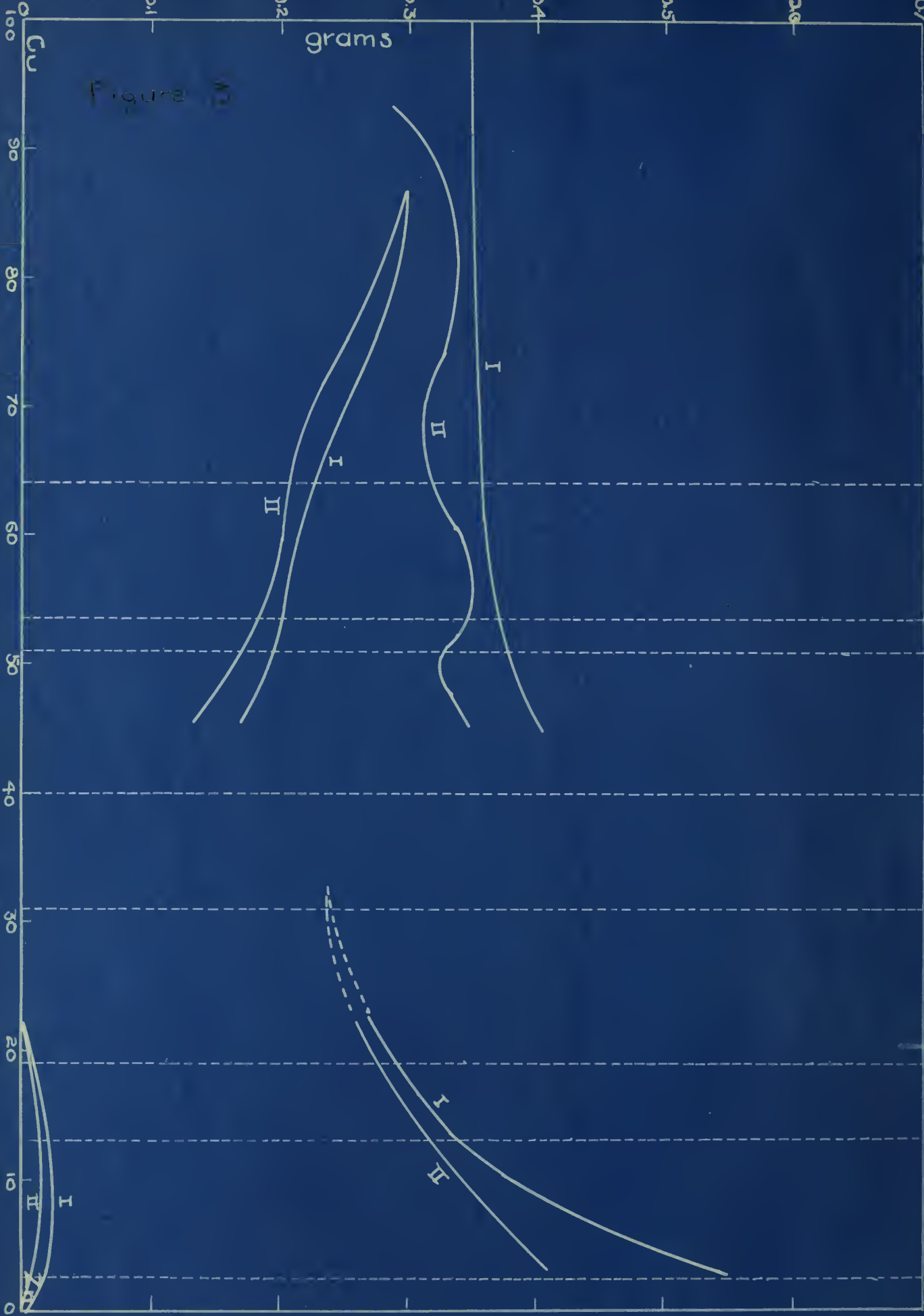


TABLE III.

Corrosion in Sodium Nitrate Solution.

% Cu.	Grams Corrosion	Grams Scale	Grams.Cu. Corrosion	Grams Cu. in Scale	% Cu. Corrosion	% Residue Cu. of total Corrosion
93.6	.3479	.2848	----	----	----	----
86.6	.3538	.3371	.2964	.2952	.86.6	86.1
83.2	.3428	.3379	.2943	.2888	83.1	81.6
76.3	.3596	.3355	.2690	.2542	74.8	70.1
73.4	.3616	.3212	.2671	.2414	73.9	66.8
66.5	.3549	.3092	.2290	.2110	64.5	59.5
60.3	.3621	.3386	.2157	.2081	59.6	57.5
56.8	.3616	.3494	.2038	.1973	56.3	54.6
51.3	.3750	.3289	.1987	.1650	53.0	44.0
47.6	.3866	.3327	.1840	.1512	47.6	39.1
22.6	.2797	.2565	----	----	----	----
10.5	.3649	.3297	.0258	.0163	7.1	4.5
3.1	.5520	.4052	.0202	.0044	3.7	0.8

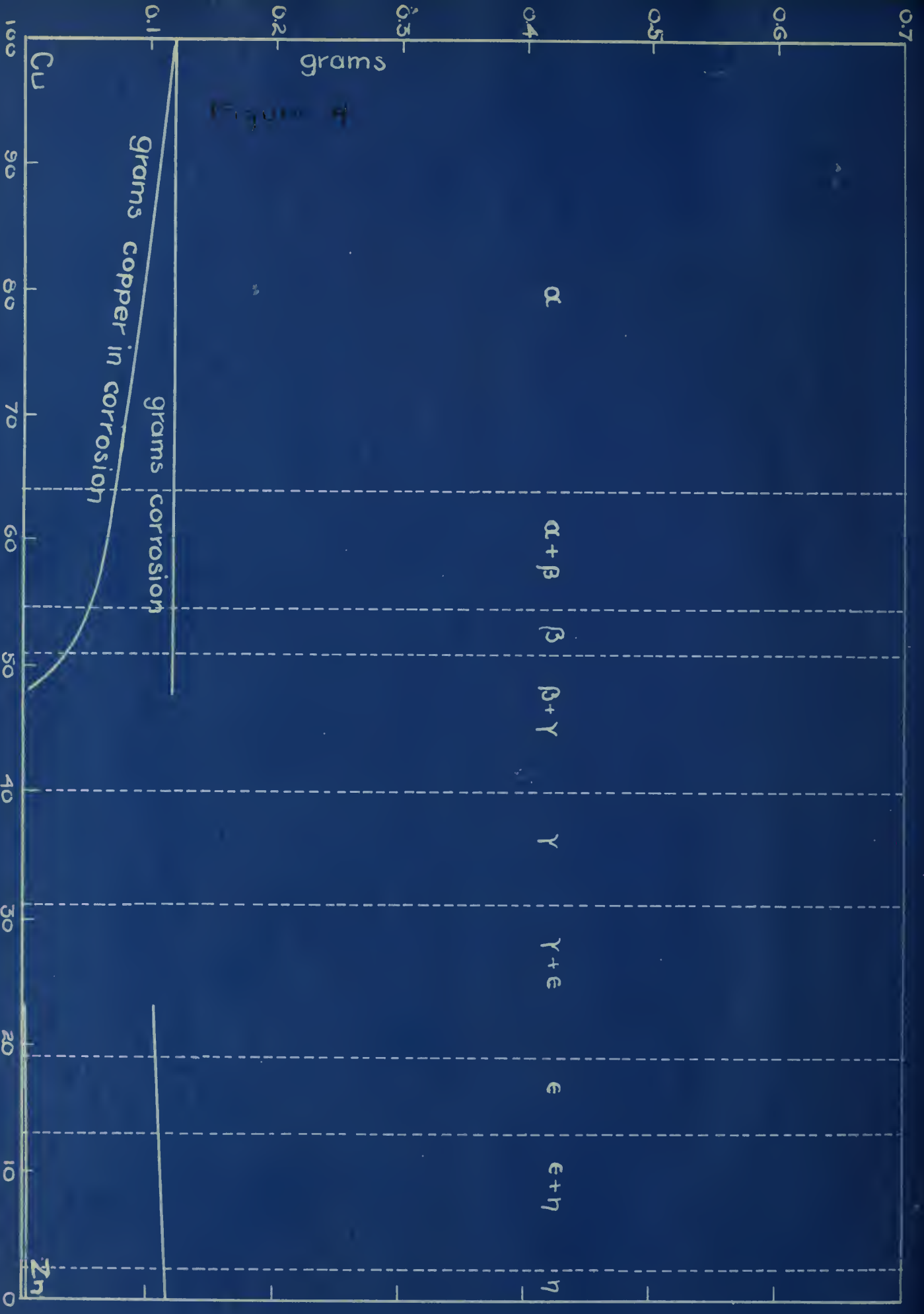
It is therefore apparent that the high corrosions in the low copper brasses are due to disintegration. The pure copper electrode was coated with an easily removable scale which exposed a bright metallic surface. This would account for the excess of copper corroded over the amount deposited; and at the same time give some insight into the results contained in Table II, which on the current efficiency basis give values greater than 100 per cent. The copper corrosion, however, decreases regularly, so that a prolongation of the curve would probably cut the copper axis at about 45 per cent. Again we see that the γ phase influences the copper corrosion very greatly; only in this case the β crystals are dissolved from the mixture of $\gamma + \beta$, whereas in the case of the sodium chloride they were not.

To determine whether the scale stood in any relation to the corrosion, an experiment was run similar to the one described above, except that an attempt was made to separate the scale from the rest of the corrosion product. This was done by dissolving the hydroxids in very dilute sulphuric acid, and immediately filtering off the scale onto weighed filter papers. The scale was then dried, weighed and analyzed separately from the first solution of the hydroxids. The data are gathered in Table III. Column 1 gives the percentage of copper in the test-piece; column 2, the total corrosion; column 3, the total corrosion minus the weight of the scale; column 4, the total copper corrosion; column 5, the total copper corrosion minus the copper in the scale; column 6, the per cent. of copper in the total corrosion; column 7, the per cent of copper in the total corrosion due to

TABLE IV.

Corrosion in Sodium Sulphate Solution.

% Cu.	Grams Corrosion	Grams Cu. Corrosion	% Cu. Corroded
93.6	.1184	.1069	90.3
86.6	.1184	.1012	85.5
83.3	.1177	.0888	75.5
76.3	.1192	.0907	76.1
73.4	.1188	.0845	71.2
66.5	.1192	.0756	63.4
60.3	.1214	.0688	56.7
56.8	.1172	.0515	44.0
51.3	.1136	.0357	31.4
47.6	.1132	.0015	1.3
22.6	.1031	.0010	0.97
10.5	.1094	.0003	0.28
3.1	.1116	.0002	0.18



the copper in the hydroxid precipitate. The data are graphically represented in Figure 3. No apparent relation exists between the grams corrosion and the scale, although it is interesting to note that the prolongation of the curves I and II for the low copper brasses would meet at about 32 per cent. copper, where there would be no corrosion scale. For the low copper brasses, the copper in the corrosion product is mainly due to the copper in the scale.

Table IV contains the results of corrosion in a normal sodium sulphate solution. In this case also, the pieces were coated with a red scale. The corrosion products were of the same nature as in the sodium nitrate solutions. From the curves in Figure 4, it is evident that the amount of corrosion is practically the same for all brasses. Below 70 per cent., the brasses soon become copper rich, until at 47 per cent., the corrosion is practically due to the zinc and remains so for all brasses down to pure zinc. Here again we have a marked change in the character of the corrosion product at the appearance of the Y crystals.

Differing in character from the preceding corrosions is that in the ammonium oxalate solutions; the data for which are given in Table V and Figure 5. At first, all of the brasses were employed in the experiment, but the current soon decreased to almost nothing, even when 110 volts were impressed. The explanation of this lies in the fact that the low copper brasses develop insulating films which do not break down even under high voltages. Consequently all of the brasses below 47 per cent. copper were

removed, whereupon the corrosion proceeded as in the other cases. The total corrosion increases with the decrease of copper content in the brass, reaches a maximum at about 60 per cent. and then decreases very rapidly. A prolongation of the curve would reach the copper axis at about 40 per cent., showing again the influence of the γ phase on the corrosion. The copper corrosion decreases rather regularly for a time and then drops very rapidly. It, too, would touch the copper axis at about 40 per cent. copper. For this electrolyte, the current efficiency curve would indicate that the efficiencies would be somewhat above 100 per cent.

Many series were run using as the electrolyte a mixture of 3 per cent. ammonium oxalate and 3 per cent. oxalic acid, but the results were so very discordant, that it was thought best to defer a discussion of this corrosion until more accurate data are available. The same is true for the normal sodium phosphate solutions. In these two cases, the current fell off very rapidly, so that after the corrosion had continued a few minutes not more than a few mill-amperes of current flowed through the cells. The voltage was then increased to 110, producing a slight increase in the current, which soon dropped to its former value. The drop in voltage was roughly estimated from cell to cell. In one case, for the acid oxalate solution, the drop for the 47.6 per cent. brass was 40 volts and for the 51.3 per cent. brass, 20 volts. Likewise, in the phosphate solutions, the 10.5 per cent. brass caused a drop of 60 volts. Therefore, in certain cases, excellent insulating films are developed, which will not break down under very high impressed voltages.

TABLE V.

Corrosion in Ammonium Oxalate Solution.

% Cu.	Grams Corrosion	Grams Cu. Corrosion	% Cu. Corroded
93.6	.4399	.4095	93.1
86.6	.4321	.3712	85.9
83.2	.4422	.3624	81.9
76.3	.4677	.3542	75.7
73.4	.4726	.3459	73.2
66.5	.4958	.3219	64.9
60.3	.4753	.2818	59.3
56.8	.5481	.3114	56.8
51.3	.4919	.2447	49.7
47.6	.4416	.2139	48.4

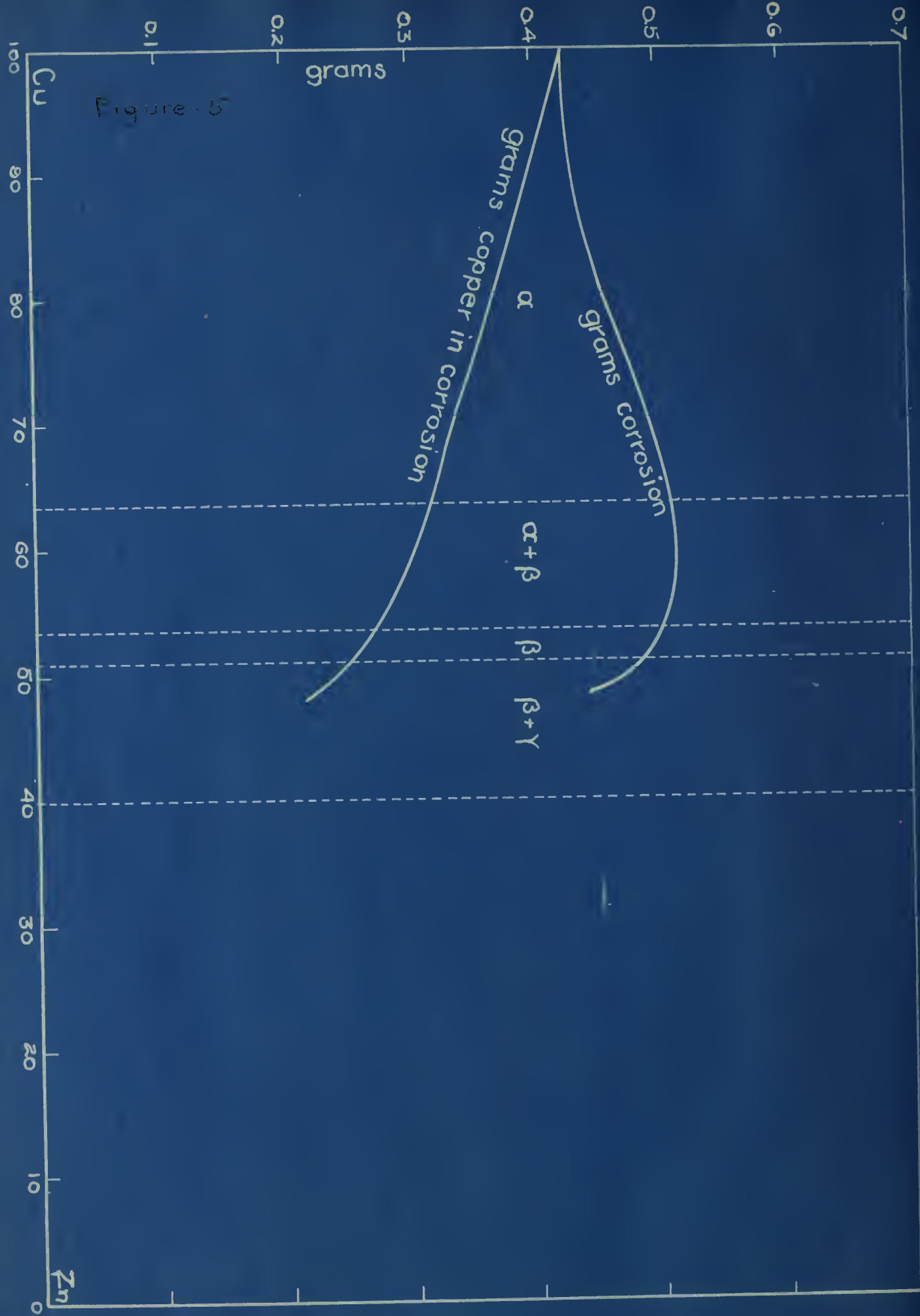


TABLE VI.

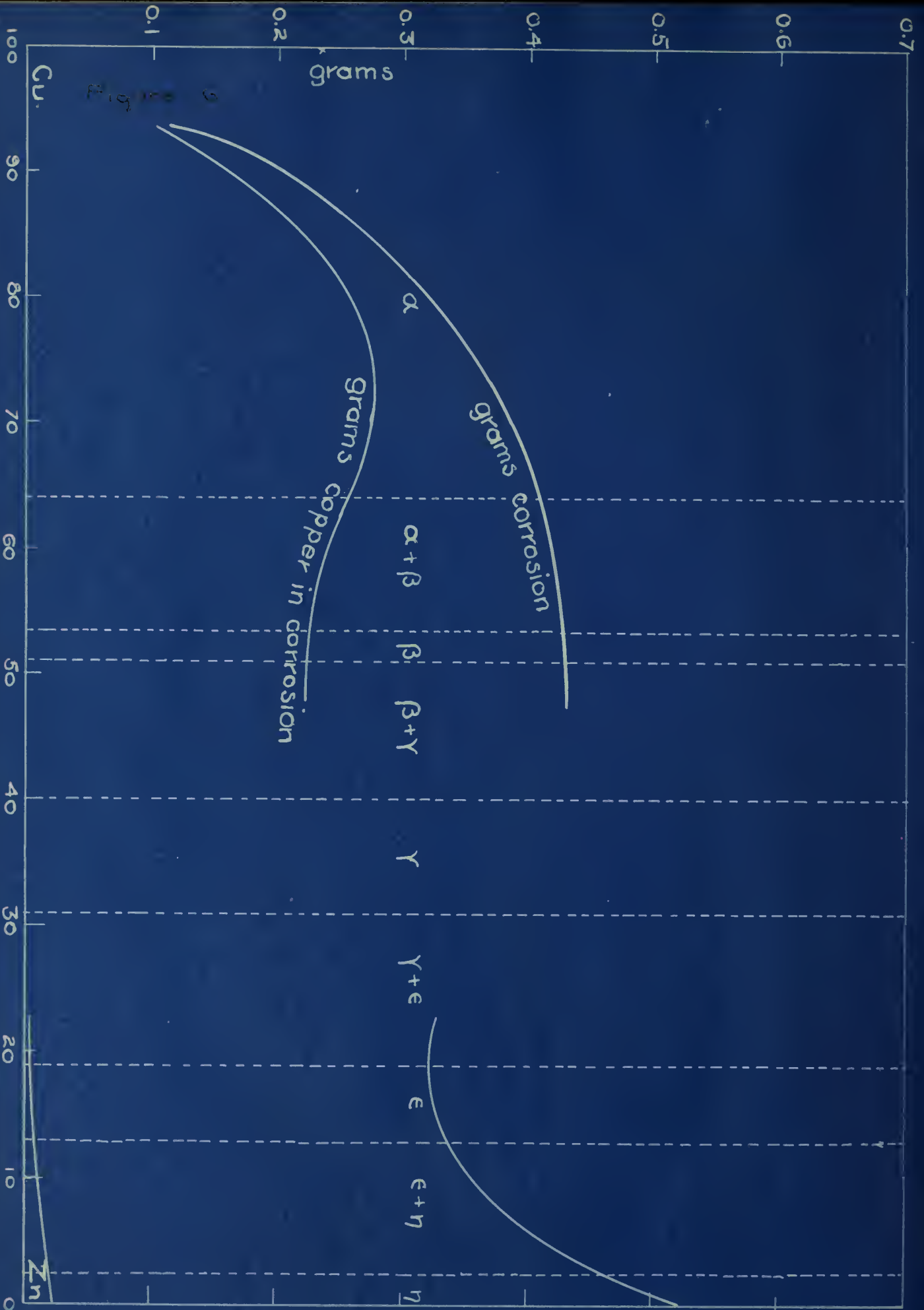
Corrosion in Sodium Carbonate Solution.

% Cu.	Grams Corroded
93.6	.0022
86.6	.0015
83.3	.0019
76.3	.0040
66.5	.0018
60.3	.0022
56.8	.0046
51.3	.0066
47.6	.0158
22.6	.0191
10.5	.0032
3.1	.0095

TABLE VII.

Corrosion in Sodium Acetate Solution.

% Cu.	Grams Corrosion	Grams Cu. Corrosion	% Cu. Corroded
93.6	.1107	.1036	93.6
86.6	.2656	.2311	87.0
83.2	.2623	.2139	81.5
76.3	.3710	.2785	75.1
73.4	.3661	.2719	74.3
66.5	.4021	.2668	66.3
60.3	.4094	.2397	58.5
56.8	.4120	.2247	54.5
51.3	.4397	.2249	51.1
47.6	.4318	.2043	47.3
22.6	.3254	.0015	----
10.5	.3458	.0022	----
3.1	.4483	.0147	3.3



Brasses do not corrode to any great extent in sodium carbonate solutions, as Table VI indicates. Here, too, difficulty was experienced in getting a current through the pieces, due to the formation of insulating films. This was especially true for the 10.5 per cent. and 3.1 per cent. brasses--where a white, adherent coating formed on the surfaces. These were scraped off and after washing out all the sodium carbonate, they gave decided tests for carbonates. The cleansed pieces were replaced in the series, whereupon the current rose to 0.15 amperes, but immediately dropped to almost nothing. At the end of the test, the 51.3 per cent. and the 47.6 per cent. brasses were covered with green films, probably copper carbonate, while the other pieces were only slightly discolored.

The results for sodium acetate (Table VII and Figure 6) are rather unexpected. The grams corrosion increase very rapidly; attain a maximum at about 50 per cent copper; probably decreases gradually and then rises very rapidly. The curve is not carried beyond 93 per cent. because the exact nature of the curve is not known. This much, however, has been ascertained; the curve must ascend very rapidly and cut the ordinate axis at about 0.23 grams. A piece of pure copper in a sodium acetate solution run in series with a copper voltameter gave the following results:- .1565 grams loss against .3719 grams gain by the voltameter; and .1491 grams loss against .3497 grams gain. In these cases, as well as in that of the 93.5 per cent. loss, the electrodes remained perfectly clean and bright, without the slightest trace of a scale.

TABLE VIII.

Corrosion in Ammonium Nitrate Solution.

% Cu.	Grams Corrosion	Grams Cu. Corrosion	% Cu. Corroded
93.6	.3976	.3723	93.6
86.6	.4032	.3461	84.8
83.2	.4158	.3459	83.2
76.3	.4162	.3121	75.0
73.4	.4306	.3152	73.2
66.5	.4332	.2852	65.8
60.3	.4202	.2511	59.7
56.8	.4471	.2516	56.3
51.3	.4424	.2378	53.7
47.6	.5014	.2242	44.7
22.6	.3908	.0302	7.7
10.5	.4707	.0341	7.2
3.1	.6582	.0231	3.5

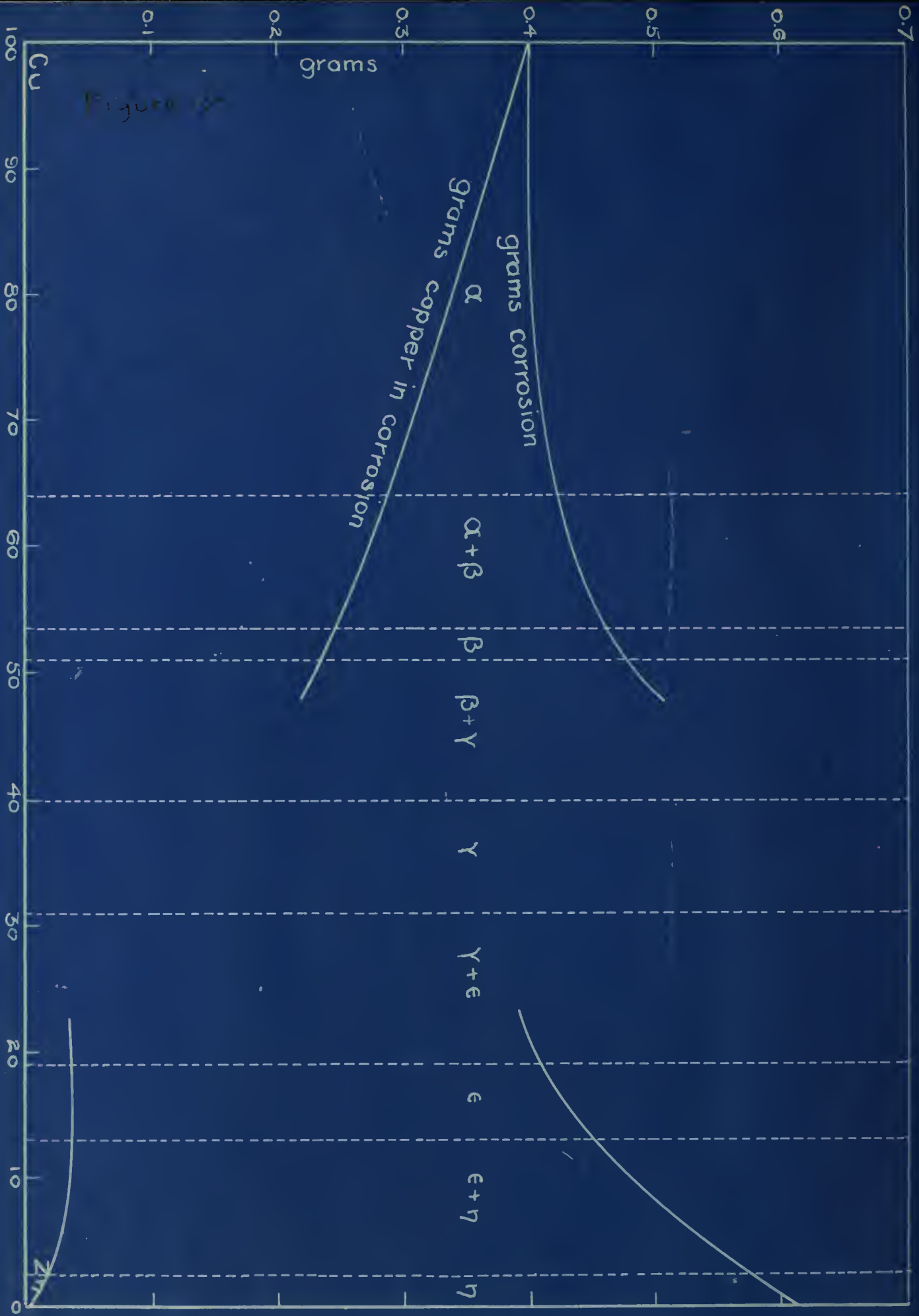
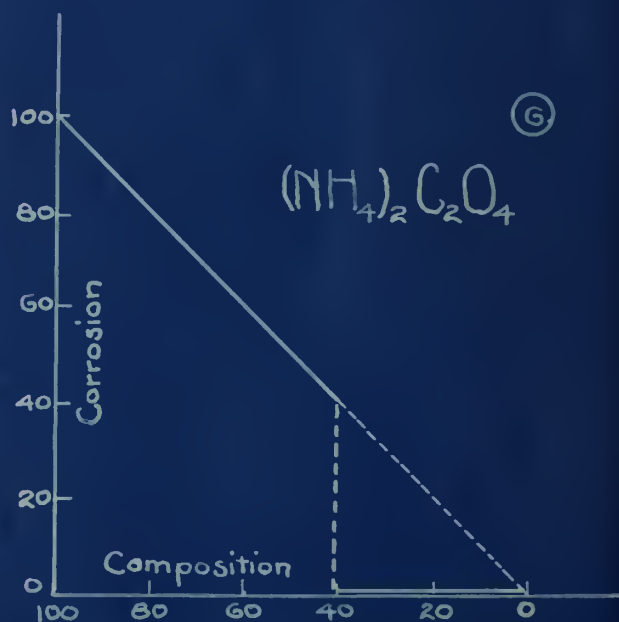
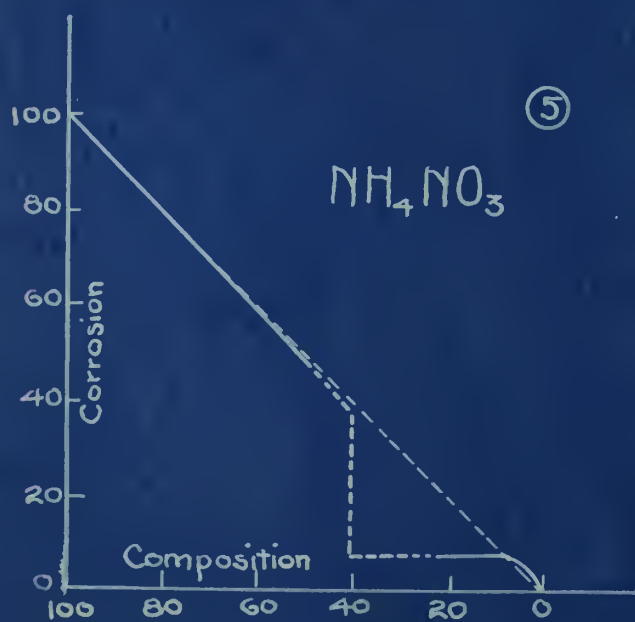
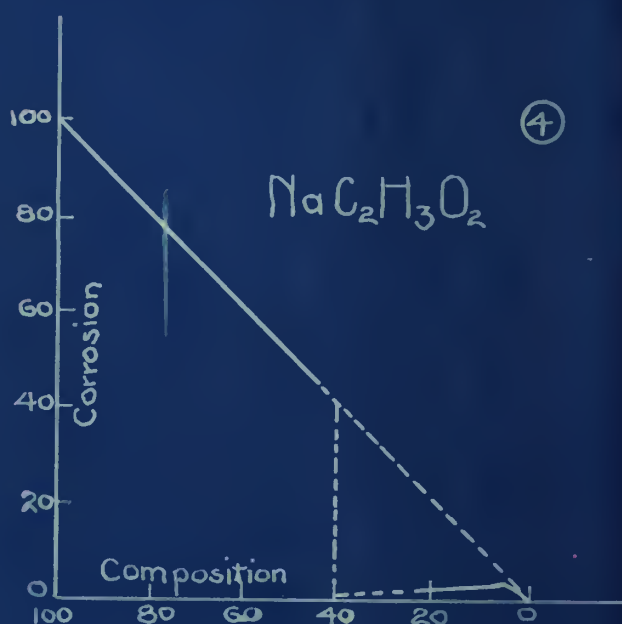
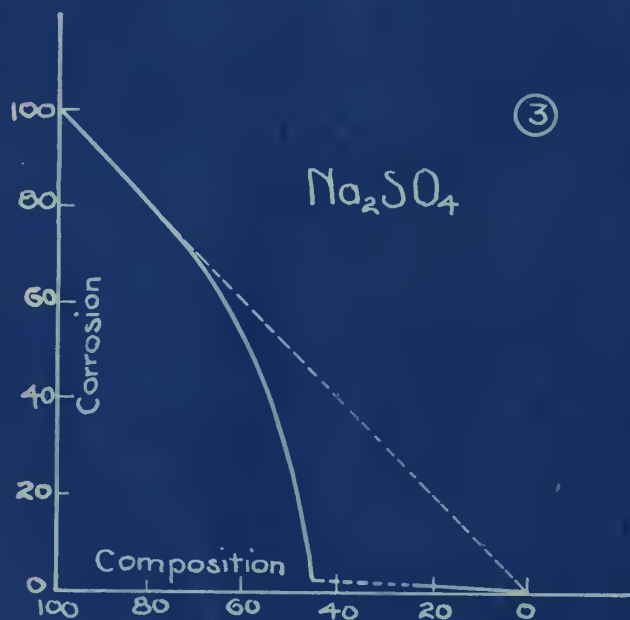
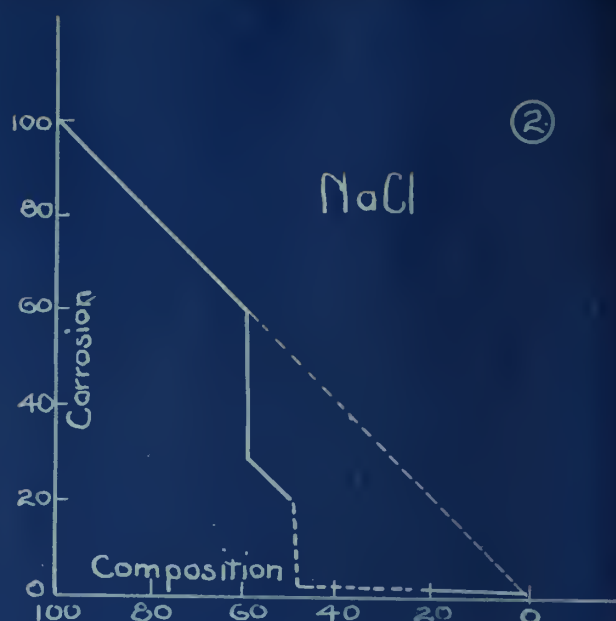
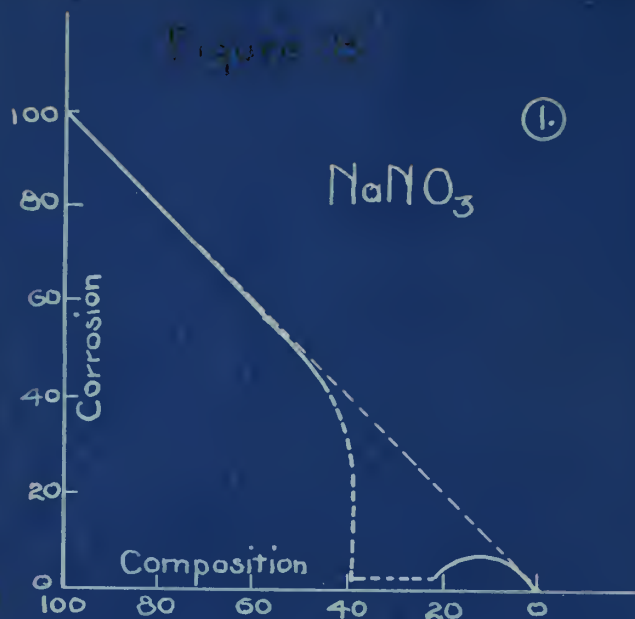


Figure 8



To determine the influence of the cation of the electrolyte on the corrosion, an experiment was performed using a normal ammonium nitrate solution. The results are embodied in Table VIII and Figure 7. In this case all of the corrosion products dissolved in the solutions, since the solutions became ammoniacal. The general character of the corrosion is the same as in the case of sodium nitrate. The larger copper content in the corrosion product of the low copper brasses from the ammonium nitrate solutions than for the sodium nitrate solutions is probably due to the chemical action of the ammonia.

In Figure 8 the relation between the composition of the test-piece and the corrosion product is clearly seen. The percentage of copper in the original test-pieces are plotted as abscissas while the per cent. of copper in the corrosion product are ordinates. If the pieces corroded in the proportion of their constituents, the curves would follow the dotted lines. In the case of sodium nitrate, the brasses corrode in the proportion of their composition down to about 50 per cent. copper; from there on, the pieces are becoming copper rich until at about 40 per cent. the corrosion product is almost pure zinc. For sodium chloride, the brasses corrode in their original compositions down to 60 per cent., then there is a very marked drop in the copper corrosion to about 50 per cent. Below that point the brasses become very decidedly copper rich. The sharp drop in the copper content at 60 per cent. might have some relation to the action of this alloy--Muntz's Metal--in sea-waters. However, the property of dissolving in the proportions of its constituents is not pe-

culiar to this alloy, but is the general behavior of all the higher copper brasses. In sodium sulphate solutions, the brasses become copper-rich below 70 per cent., and rapidly become more so, until at 45 per cent. there is practically no copper in the corrosion product. In ammonium nitrate solutions, the brasses dissolve according to their percentage composition down to 40 per cent, where there is a sudden drop in the copper content of the corrosion product. The same relations obtain in sodium acetate and ammonium oxalate solutions. In all cases, it is clearly evident that the γ crystals have a very marked effect on the amount of copper corroded. This is also true for the ϵ and α phases.

While perusing the paper by Herschkowitsch (4) on the potential differences of alloys, the great similarity between his curves for the copper-zinc alloys and our diagrams in Figure 8 was at once noticed. In Figure 13 of his paper, the potential difference rapidly decreases as the copper content of the brass decreases until at about 40 per cent. copper, the potential difference is almost equal to that of pure zinc and remains so down to 100 per cent. zinc. In our diagrams the per cent. of copper in the corrosion product rapidly decreases with the decrease of copper content in the brass, until at about 40 per cent. copper, practically no copper is corroded, and from that point down to pure zinc very little copper is found in the corrosion product. At once, the thought suggested itself that the composition of the corrosion product was dependent upon the potential differences of the various alloys. Granting this, the nature of electro-chemical corrosion could be predicted from the potential difference curves. A few preliminary

experiments were made using a normal sodium nitrate solution as the electrolyte and a piece of pure zinc as one of the electrodes, while the brass served as the other. These measurements were only quasi-quantitative in as much as the zinc was continually passing into solution, thus causing a continuous change in the voltage. Herschkowitsch, however, employed a saturated zinc sulphate solution and of course experienced no such difficulty. Our experiments were not comparable with his. Moreover, on comparing his data for copper-tin alloys with the corrosion data obtained by Curry (l.c.) no concomitance was found. Further work along this line was therefore discontinued for the present.

If chemical and electro-chemical corrosion are identical, then the same results ought to be secured by the former method as by the latter one. To test this, the brasses were corroded for four weeks in a normal sodium persulphate solution; in a similar solution with 5 per cent. excess of sodium hydrate, and a few pieces in sodium chloride solutions. A similar series was run in sodium nitrate solutions, but the corrosion was practically nothing. In all cases, air was bubbled continuously through the solutions.

The corrosion in the alkaline persulphate solution was very unsatisfactory. In most cases part of the test-pieces were in the liquid and part exposed to the air; whenever this occurred, the corrosion was only slight on the part in the liquid, but extremely deep and rough on the part in air. The experiment was discontinued since the results would not have been due to the persulphate solution. The 93.5; 83.2; and 73.4 per cent brasses

TABLE IX.

Chemical Corrosion in Sodium Chloride Solution.

% Cu.	Grams Corrosion	Grams Cu. Corrosion	% Cu. Corroded
93.6	.0866	.0713	82.2
86.6	.0692	.0565	81.6
83.2	.0571	.0456	79.9
76.3	.0168	.0126	75.0
73.2	.0131	.0095	72.5

were badly corroded on the part of the pieces exposed to the air. The 22.6 per cent. brass--a silvery-white alloy--was entirely coated with a very black deposit, which gave indications of crystallinity. The 60.3 per cent. and the 76.3 per cent. alloys remained practically unchanged. Two days after the corrosion had been started, perceptible blue colors appeared in the solutions, containing the brasses of less than 51.3 per cent. copper. This is exactly the opposite of what happened in the sodium persulphate solution; where deep blue colors developed and remained in all the flasks containing brasses with more than 51.3 per cent. copper.

The results for the corrosion in persulphate solutions were no more gratifying than in the alkaline persulphate solution. The corrosion for the high copper brasses was extremely great; the 51.3 per cent. brass was coated with a layer of copper, which must have been reprecipitated onto the piece as its diameter was much larger where the copper layer was present than where the piece remained unchanged. The portion of the piece exposed to the air was scarcely affected. The 3.1 per cent. brass was very much larger after corrosion than before, due to a hard layer of copper, in knobs and mounds, that must have been reprecipitated on to the piece. The experiment was discontinued.

The pieces in sodium chloride were covered with light green precipitates, readily soluble in nitric acid, without effervescence. The results are given in Table IX. It will be seen that in most cases, the corrosion product contained less copper than did the original test piece.

The foregoing methods for producing chemical corrosion are

unsuitable for our purposes. It is therefore proposed to corrode the brasses by various acids under conditions as nearly comparable with the electrochemical method as possible. A comparison of the rates of solution should give some insight into the passivity and perhaps the constitution of the alloys.

Of greater commercial importance than the simple alloys of copper and zinc, are the alloys containing various amounts of tin, ranging from .2 per cent. to 2.5 per cent. tin. These are especially useful for hydraulic machinery, and the other devices intended to resist corrosion by sea-water, mine-water, etc. Some of the physical properties of such brasses have been investigated by Thurston⁽⁷⁾, who calls them "Kalchoids". Guillet⁽⁸⁾ investigated micrographically a few of these alloys, and finds that one part of tin is equivalent to four parts of zinc. He says, "an important property due to the introduction of tin has been shown by numerous experiments, that of greatly increased resistance to corrosion by sea-water". We therefore decided to study the electrochemical corrosion of a few of these brasses. Accordingly, two series of brasses were cast, one containing about .75 per cent. tin and the other 1.00 per cent. tin. Their compositions are as follows:-

% Cu	% Sn	% Cu	% Sn
81.0	.78	86.9	.98

% Cu	% Sn	% Cu	% Sn
77.1	.78	77.2	.98
73.3	.76	74.8	.90
64.0	.77	71.4	1.02
58.0	.79	66.7	1.07
54.8	.75	63.0	1.05
54.7	.65		

Owing to an error in calculation, the last two brasses of the .75 per cent. series were at first thought to be of different compositions. The error was discovered too late to recast one of them; nevertheless, both brasses were used in every experiment to serve as a check.

The brasses were made by first melting the copper and then adding the zinc and tin, stirring well and pouring as described in the case of the simple brasses. All pieces were annealed at 400° C. Throughout this work the tin was estimated as stannic oxide by ignition of the sulphide. The exact procedure is given by Olsen (9). The copper was determined electro-chemically in the filtrates from the tin determinations. In the analyses of the test pieces, 3-4 grams of the alloy were used and the duplicate tin analyses were very satisfactory. However, for the analyses of the tin in the corrosion product, the quantities were usually so small, that the results tabulated below must be considered merely as approximate. The accuracy and rapidity of the work is greatly diminished by the lack of a good rapid method for determining small quantities of tin in the presence of large quantities of copper.

Corrosion tests were made in normal sodium nitrate, sodium

TABLE X A.

Corrosion in Sodium Nitrate Solution.

% Cu.	% Sn.	Grams Corrosion	Grams Cu. Corrosion	Grams Sn. Corrosion	% Cu. Corroded	% Sn. Corroded
54.7	.65	1.6118	.8878	.0120	55.1	.73
54.8	.75	1.6030	.8666	.0151	54.0	.94
58.0	.79	1.6494	.9546	.0151	57.9	.92
64.0	.77	1.6471	1.0524	.0119	64.0	.72
73.3	.76	1.5651	1.1492	.0204	73.4	1.30
77.1	.78	1.5850	1.1806	.0155	74.5	.98
81.0	.78	1.5758	1.2669	.0241	80.4	1.53
63.0	1.05	1.6520	1.0304	.0128	62.4	.77
66.7	1.07	1.6585	1.1162	.0162	67.2	.98
71.4	1.02	1.5640	1.1126	.0198	71.1	1.26
74.8	.90	1.5958	1.1958	.0188	74.9	1.18
77.2	.94	1.5155	1.1350	.0183	74.9	1.21
86.9	.98	1.5520	1.3312	.0137	85.8	.88

TABLE X B.

54.7	.65	1.3280	.7262	.0089	54.7	.68
54.8	.75	1.3633	.7504	.0147	55.0	1.08
58.0	.79	1.3880	.8124	.0120	58.5	.86
64.0	.77	1.3768	.8809	.0155	64.0	1.13
73.3	.76	1.4118	1.0404	.0133	73.7	.95
77.1	.78	1.3708	1.0696	.0123	78.0	.90
81.0	.78	1.3599	1.0982	.0192	80.8	1.41
63.0	1.05	1.3767	.8676	.0141	63.0	1.03
66.7	1.07	1.4381	.9570	.0160	66.6	1.11
71.4	1.02	1.3577	.9646	.0144	71.1	1.06
74.8	.90	1.3975	1.0524	.0128	75.3	.93
77.2	.94	1.2989	.9732	.0135	75.0	1.04
86.9	.98	1.3341	1.1682	.0122	87.6	.92



TABLE XI A.

Corrosion in Sodium Sulphate Solution:

% Cu.	% Sn.	Grams Corrosion	Grams Cu. Corrosion	Grams Sn. Corrosion	% Cu. Corroded	% Sn. Corroded
54.7	.65	.8812	.4875	.0036	55.3	.41
54.8	.75	.8794	.4802	----	54.6	----
58.0	.79	.8826	.5194	.0043	58.9	.50
64.0	.77	.8796	.5642	.0071	64.1	.81
73.3	.76	.8711	.6250	.0025	71.8	.40
77.1	.78	.8706	.6832	.0077	78.5	.89
81.0	.78	.8679	.7014	.0067	80.8	.77

63.0	1.05	.9097	.5729	.0095	63.0	1.04
66.7	1.07	.8733	.5841	.0070	66.9	.79
71.4	1.02	.8662	.6111	.0096	70.6	1.10
74.8	.90	.8719	.6591	-----	75.6	----
77.2	.94	.8706	.6678	.0040	76.7	.45
86.9	.98	.8664	.7605	.0056	87.8	.65

TABLE XI B.

54.7	.65	.8564	.4715	.0041	55.1	.49
54.8	.75	.8884	.4788	.0043	54.0	.46
58.0	.79	.8458	.4888	.0063	57.8	.75
64.0	.77	.8349	.5209	.0091	62.4	1.09
73.3	.76	.8347	.6661	.0093	73.8	1.12
77.1	.78	.8322	.6425	.0053	77.2	.63
81.0	.78	.8317	.6739	.0117	81.0	1.40
63.0	1.05	.8539	.5367	.0078	62.9	.92
66.7	1.07	.8412	.5509	.0112	65.5	1.33
71.4	1.02	.8370	.5967	.0030	71.3	.35
74.8	.90	.8342	.6241	.0114	74.8	1.37
77.2	.94	.8373	.6466	.0091	77.2	1.09
86.9	.98	.8316	.7264	.0118	87.4	1.42

sulphate and sodium chloride solutions. Each series was run in duplicate. Table X and Figure 9 give the results for sodium nitrate solutions. As above no effort was made to keep the current uniform throughout the different series; our aim being to get a large corrosion product. The curves are plotted in such a way that any ordinate, within the limits of the experiment will show the per cent. of copper in the 1.00 per cent. tin brasses and the 0.75 per cent. tin brasses, that will give the same amount of corrosion. In this way it was hoped that the influences of small amounts of tin on the corrosion could be detected. In all cases the curves marked (a) refer to the copper corrosion; those marked (b) to the total corrosion.

For the .75 per cent. tin brasses, there is a marked increase in the amount of corrosion, as the per cent. of copper decreases; this is in accord with the results for the simple brasses in sodium nitrate. For the 1.00 per cent. tin brasses the increase is not so marked though no less real. A brass containing 70 per cent. copper and 1.00 per cent. tin corrodes as much as a brass containing 75 per cent. copper and .75 per cent. tin; in the same manner, a brass of 65 per cent copper and 1.00 per cent. tin and one of 50 per cent. copper and .75 per cent. tin would corrode equally. Or in general, in sodium nitrate solutions, to produce the same amount of corrosion, the higher the tin content, the higher must be the copper content also.

The same rule does not obtain in sodium sulphate solutions as Table XI and Figure 10 clearly show. In this case, the amount of corrosion remains practically constant, agreeing with the re-

TABLE XII A.

Corrosion in Sodium Chloride Solution.

% Cu.	% Sn.	Grams Corrosion	Grams Cu. Corrosion	Grams Sn Corrosion	% Cu. Corroded	% Sn. Corroded
54.7	.65	.5123	.2779	.0041	54.2	.80
54.8	.75	.5167	.2886	.0041	55.8	.79
58.0	.79	.5241	.3033	.0046	57.9	.87
64.0	.77	.5447	.3443	.0042	63.2	.77
73.3	.76	.5910	.4350	.0042	73.6	.71
77.1	.78	.5906	.4598	.0059	77.9	1.00
81.0	.78	.6192	.4977	.0055	80.4	.89
63.0	1.05	.5519	.3484	.0043	63.1	.79
66.7	1.07	.5568	.3678	.0086	66.1	1.54
71.4	1.02	.5674	-----	-----	-----	-----
74.8	.90	.5881	-----	-----	-----	-----
77.2	.94	.6076	.4716	.0055	77.6	.91
86.9	.98	.6498	.5707	.0075	87.8	.89

TABLE XII B.

54.7	.65					
54.7	.65	.6941	.3793	.0040	54.5	.57
54.8	.75	.6944	.3809	.0061	54.9	.88
58.0	.79	.6861	.4047	.0036	59.0	.93
64.0	.77	.7298	.4719	.0054	64.7	.74
73.3	.76	.7599	.5593	.0047	73.6	.83
77.1	.78	.7808	-----	-----	-----	-----
81.0	.78	.7895	.6405	.0040	81.1	.52
63.0	1.05	.7529	.4751	.0073	63.1	.93
66.7	1.07	.7545	.5067	.0078	67.2	.49
71.4	1.02	.7597	.5445	.0072	71.7	1.03
74.8	.90	.7464	.5519	-----	73.9	-----
77.2	.94	.7808	.6029	.0061	77.2	.78
86.9	.98	.8462	.7324	.0042	86.6	.49

TABLE XIII.

Comparative Corrosions.

% Cu.	% Sn.	Grams of Corrosion					
		NaCl		NaNO ₃		Na ₂ SO ₄	
		1	2	1	2	1	2
73.4	0.00	.4509	.9879	.3108	.7190	.2876	.6293
73.3	0.76	.4486	.9827	.2992	.6739	.2886	.6307
74.8	0.90	.4477	.9636	.2969	.6815	.2886	.6304

sults for the simple brasses. The tin seems to have no influence on the amount of corrosion or its copper content.

In sodium chloride solutions, the brasses behave differently than in either the sulphate or the nitrate solutions. (Table XII and Figure 11) The amount of corrosion decreases with decreasing copper content, as in the case of the simple brasses. The influence of the tin is very marked. A brass, containing 60 per cent. copper and 1.00 per cent. tin corrodes as much as a brass of 71 per cent. copper and .75 per cent. tin; or one of 70 per cent. copper and 1.00 per cent. tin as much as one of 80 per cent. copper and .75 per cent. tin. In this case, the greater the tin content, the copper remaining constant, the greater the corrosion. However, there is a limit to the amount of tin that can be added, due to the mechanical properties of these brasses.

In order to verify the foregoing conclusions, and to obtain some idea of the relative corroding power of the various electrolytes, the following experiment was performed. Three brasses of approximately the same copper content, but of different tin content, were corroded in the sodium sulphate, sodium nitrate and sodium chloride solutions, by the same current. The results are given in Table XIII. It will be seen that the conclusions drawn above have been verified; in the sodium sulphate solution the corrosion is constant; in sodium nitrate, it decreases with increase of tin. The results for sodium chloride are just the opposite of what was expected.

If we accept the values for sodium sulphate as the theoretical amounts, when copper is divalent and zinc divalent, then in

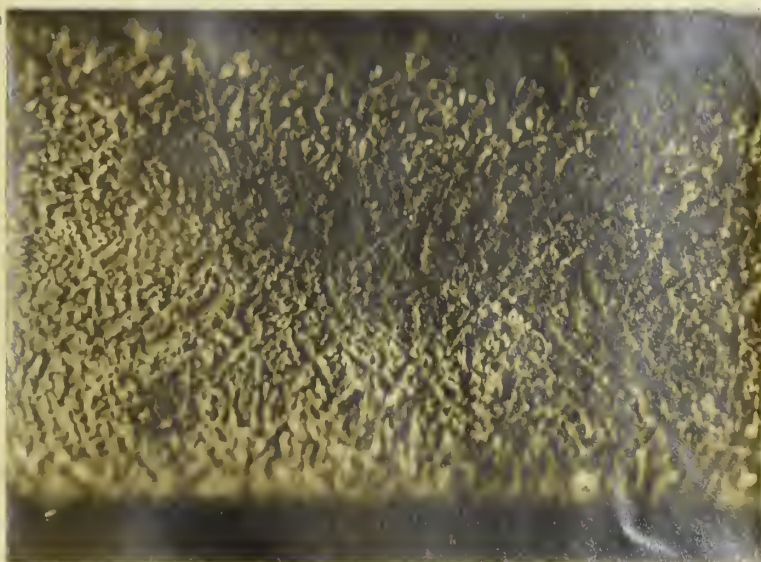


Figure-12



Figure -13



Figure - 14

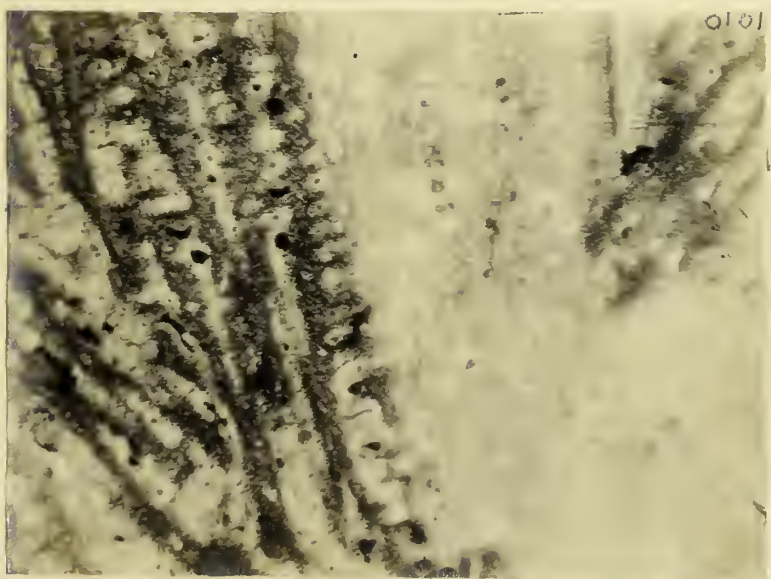


Figure - 15

sodium nitrate solutions, the brasses dissolve more rapidly than would be expected.; while in sodium chloride solutions, the efficiency is far below the theoretical, assuming the copper to dissolve in cuprous form.

Finally, we present photographs of a few corroded pieces, and the micrographs of the corresponding brasses. Although the magnifications in the series are different, that for the corroded specimens being about $\times 14$, while for the micrographs it is $\times 87$, a comparison of the results of both methods of etching yields interesting results. Figure 12 represents the appearance of the 93.5 per cent. brass after corrosion in ammonium nitrate solution. There is nothing very characteristic about the corrosion, just what we would expect from Figure 13, which is the nitric acid etched micrograph of a similar brass. From the latter figure we see that the annealed brass consists of large uniform lobes of  crystals, which would all corrode at the same rate. In Figure 14, we have the appearance of the 76.3 per cent. brass after corrosion in sodium chloride solution. The dendritic structure is very apparent. The areas of varied brightness are due to differences in the reflection of the light from the various crystalline faces. The micrograph of this brass (Figure 15) would confirm in a general way the appearance of Figure 14. The light portion is one crystalline face; the dark portion another. The dendritic structure is also visible in the figure. Probably the corroded specimen of most striking appearance is that of the 56.8 per cent. brass as shown in Figure 16, for a sodium chloride solution.

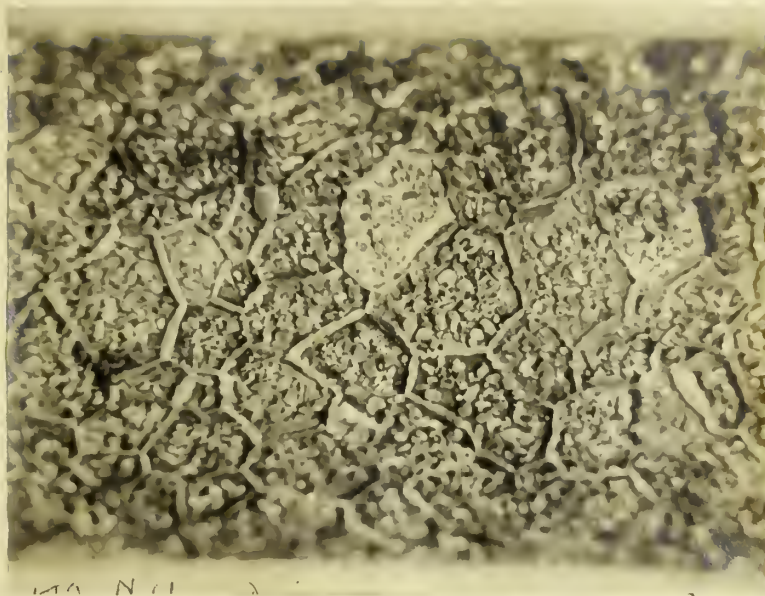


Figure-16

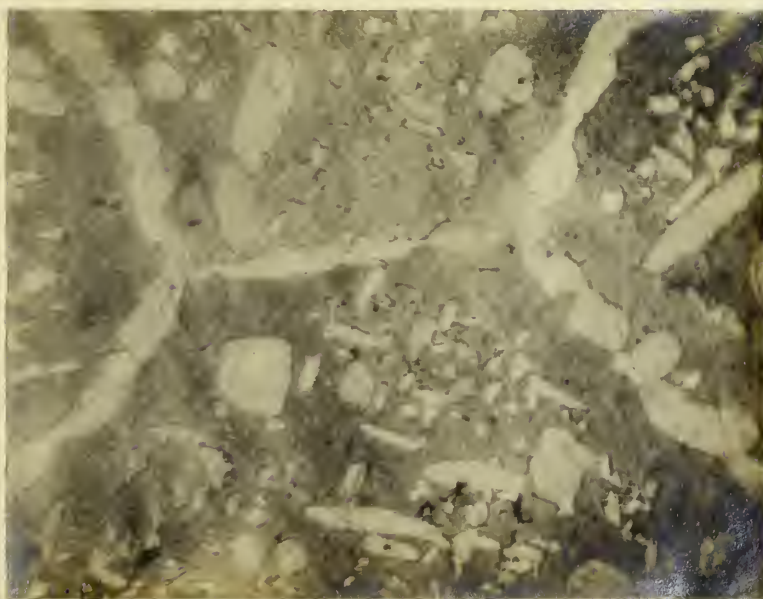


Figure-17

The surface of the piece was covered with a net-work of crystals, sharply separated from one another by thick, raised borders. Within each crystal, some parts have been eaten away, leaving a mass of smaller crystals. Acid corrosion gives the same result, as Figure 17 very clearly demonstrates.

In this figure we see the boundary crystals in detail and notice that they are not single crystals, but a line of many smaller ones. According to Shepherd's classification, a 56.8 per cent. brass is a mixture of α and β crystals. It is probable that the smaller crystals are of the β variety, while the large areas are α crystals, breaking down into β . At this point the question naturally arises; what are the small crystals? Are they a compound or a mixture? It would be a hopeless task to mechanically pick out a few crystals and analyze them; although a test piece could be made of such dimensions as to render such a problem feasible. However, our corrosion data show us this much: in sodium chloride solution, the corrosion product contained only 25.1 per cent. copper as against 56.8 per cent. in the original test piece; and there remained no film of copper after corrosion. In all other electrolytes, the composition of the corrosion product agreed with that of the original test-piece. Therefore, we cannot explain the peculiar structure from our electrochemical data.

Another striking corrosion is illustrated in Figure 18. It is for a 47.6 per cent. brass in a sodium nitrate solution. The picture does not adequately convey a true conception of the appearance of the test-piece. The surface was sharply divided into small areas, by raised outlines. The areas were not flat, but



Figure-18

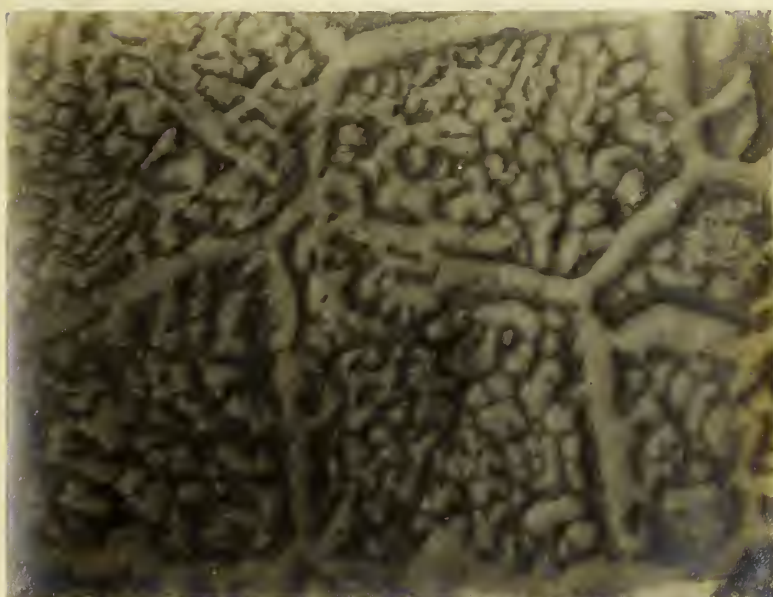


Figure-19

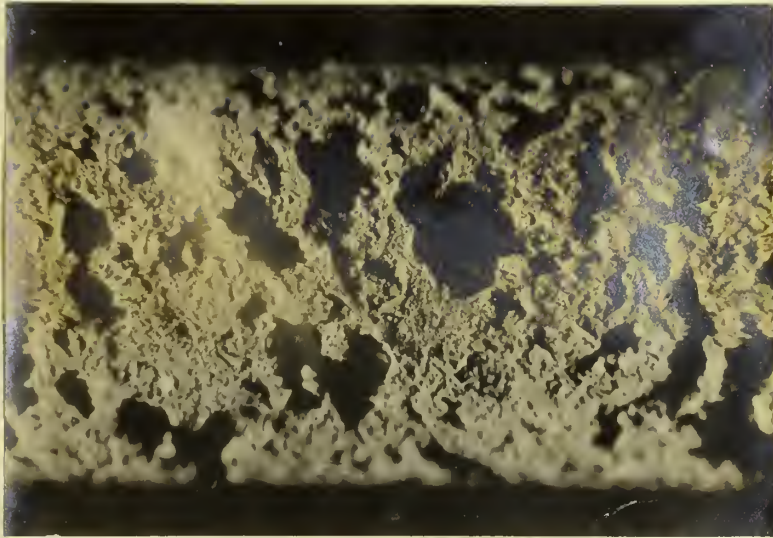


Figure-20

were cup-shaped, giving one the impression that certain portions of the piece had been gouged out. That some such corrosion would occur could have been predicted from the micrograph of the brass (Figure 19). A remarkable fact about this brass is that no etching was required; the photograph was taken from the polished specimen. The cell like structure is very apparent. Such a brass contains β and γ crystals. Again we are brought face to face with the difficult problem of differentiating the various crystals and determining their constitution. Electrochemical corrosion sheds some light on the question. Only 1.3 per cent. copper are found in the corrosion product; whereas the original brass contained 47.6 per cent. Moreover, the grams corrosion indicate that the test piece reacted as though it were almost pure zinc. We must therefore conclude that the copper is combined in such a manner as to form an insoluble; i. e., a relatively non-corrosive alloy. The crystals cannot be pure copper, because we know that pure copper under the same conditions corrodes readily. To illustrate the deep disintegration that often occurred in the low copper brasses, we include a photograph (Figure 20) of the 3.1 per cent. brass after corrosion in sodium nitrate solution. The micrograph did not reveal anything characteristic and was therefore omitted.

The equilibrium diagram for copper-tin-zinc alloys has not been worked out. From an inspection of the following photographs, it is readily seen that small percentages of tin have but little effect on the appearance of the test-pieces. A brass containing 81 per cent. copper and .78 per cent. tin presents much the same appearance (Figure 21) as does the simple brass having 76.3



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Figure-21

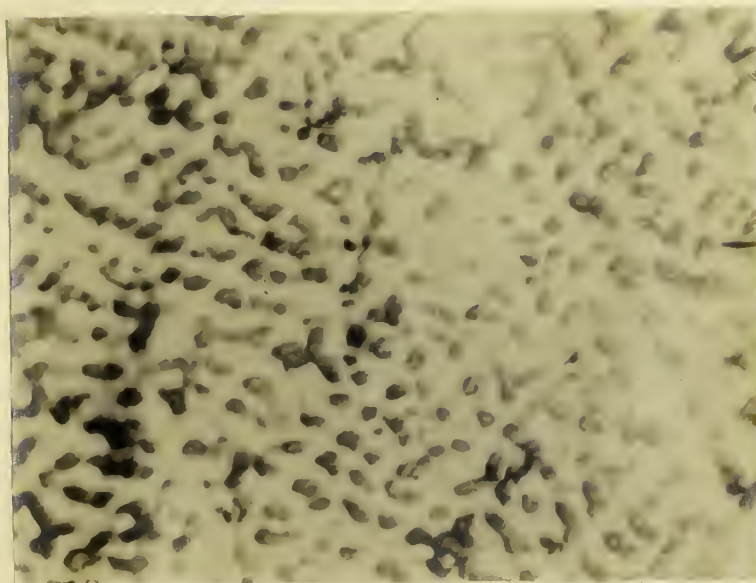


Figure-22



Figure-23



Figure 24

per cent. copper (Figure 14). A micrograph of the same alloy reveals the peculiar structure, shown in Figure 22. Of all the Kalchoids, none surpassed the 54.7 per cent copper and .65 per cent. tin alloy in appearance after corrosion. Figure 23 represents such a test-piece corroded in a sodium sulphate solution, although the same effect may be obtained in sodium chloride or sodium nitrate solutions. The rough surface is due to large rectangular crystals, golden in color, giving a most beautiful effect in sunlight. A comparison of this picture with that for the simple brass of 56.8 per cent. copper content (Figure 16) reveals many points of similarity between the two; although the Kalchoid has not the symmetry of the simple brass. The micrograph of the Kalchoid (Figure 24) is almost identical with that shown in Figure 17. For this brass also, electrochemical corrosion has given us but little insight into the actual changes of the test piece. Some portions have been eaten away; while others apparently remained unchanged, yet the corrosion product contains the same per cent. of copper as the original test piece.

Summary.

In this research we have prepared brasses of varying composition, and have studied the electrolytic corrosion of these in salt solutions; e.g. sodium chloride, sodium nitrate, sodium sulphate, ammonium nitrate, sodium carbonate, sodium acetate, ammonium oxalate, ammonium oxalate plus oxalic acid, and sodium phosphate.

We have shown that in sodium chloride solutions, the amount of corrosion decreases with decreasing copper content of the brass;

in sodium sulphate solutions, it remains constant; while in sodium nitrate solutions, it increases.

The α and β brasses seem to have but little effect on the corrosion. The γ , ϵ and η brasses prevent the copper from corroding; but have little restraining effect on the zinc. No brass becomes passive in the more common salt solutions.

Chemical corrosions have been attempted but the results are unsatisfactory.

Two series of copper-tin-zinc brasses were prepared; one containing .75 per cent. tin and the other 1.00 per cent. tin. These have been corroded in solutions of sodium sulphate, sodium nitrate and sodium chloride.

The addition of tin to a brass has no effect on the amount of corrosion in sodium sulphate solutions; in sodium nitrate solutions, it slightly decreases the corrosion; in sodium chloride, it slightly increase the corrosion.

Photographs were taken of the appearance of the electrodes after corrosion; and these were compared with micrographs of similar brasses.

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